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PRELIMINARY TESTS WITH THE CHESTBAND

Narayan Yoganandan, PhD, David Skrade, M.S., Frank Pintar, PhD,

John Reinartz, MS, Anthony Sances, Jr., PhD

Department of Neurosurgery, Medical College of Wisconsin,
8700 West Wisconsin Avenue, Milwaukee, WI 53226
Department of Veterans Affairs Medical Center, Milwaukee, WI 53295
Department of Biomedical Engineering, Marquette University,
Milwaukee, WI 53233

ABSTRACT

The objective of the present study was to develop a protocol for obtaining appropriate experimental strain gauge data using the newly developed External Peripheral Instrument for Deformation Measurement, hereinafter called the chestband. Tests were conducted to determine the effects of chestband data with different excitation voltages and drift characteristics of each gauge over a period of 10 hours. In-house calibration tests that can be used prior to and following each sled test with human surrogates, and quasistatic and dynamic (horizontal deceleration) tests at different velocities were also conducted with the chestband. Results indicated that drift patterns did not demonstrate any particular bias with injury excitation voltages of 4 V and 10 V. Furthermore, the maximum drift in any individual gauge for either voltage over a period of 10 hours was within 1.2%. Pronounced drift was observed during the first 10-30 minutes suggesting that the instrument needs an initial stabilization time. The methodology for using the chestband in sled impact tests should include, in addition to the stabilization time, a zeroing and calibration on a flat surface followed by instrumenting the chestbands just prior to the run on the surrogate chest.

INTRODUCTION

Investigations into the tolerance of the human thorax have been routinely conducted using experimental animals, tests with human cadavers, and mathematical analogues. Mechanical parameters such as the force acceleration, pressure, velocity, and maximum chest compression have been identified as potential indices for specifying the thresholds of trauma. These biomechanical variables have been used to develop safety regulations and design anthropomorphic test devices such as the Hybrid III manikin to predict injury in crash environments.

The human chest is a complex anatomical entity primarily consisting of the heart, great blood vessels, nerves, trachea, esophagus, and other tissues. Osseous anatomy of the chest represents a flexible, deformable structure with sufficient compliance to protect internal vital organs housed within. Under external forces typically encountered in motor vehicle collisions, with particular reference to frontal impact, the human thorax undergoes compressive deformations. This may be due to blunt trauma arising from chest contact with the interior of the automobile, active restraint loads transferred to the chest, or inertial effects. Compressive force from blunt trauma causes the anterior thoracic bony elements to deform, exhibit fracture, impinge on the vascular structure and other soft tissues, or may even induce secondary impact to the vertebral column. Serious injuries such as laceration of the heart, lungs, and traumatic rupture of the aorta leading to traumatic asphyxia and fatality, are also common.

It is well known in biological materials, such as the human thorax, that the tissue is non-linear, and exhibits non-uniform deformation characteristics. Therefore, a single index such as acceleration (60 G) may not be completely adequate to define the tolerance of the human thorax. Because chest injury often occurs secondary to its deformations due to external traumatic forces (described above), it may be necessary to document the deformations at various locations and levels of the thorax during an impact event. These localized deformations and the associated documentation of internal injuries will assist in a better definition of the tolerance. Changes in the chest contours obtained using the localized deformation histories may also facilitate in an understanding of the mechanism of injury and guide the design of anthropomorphic test devices with improved biofidelity.

An External Peripheral Instrument for Deformation Measurement (EPIDM) has been designed and developed by the National Highway Traffic Safety Administration (NHTSA) to record the localized deformation and to compute the ensuing chest contours in simulated motor vehicle collisions. The purpose of the present study was to develop a methodology to use the EPIDM (also called the chestband) in sled tests with anthropomorphic test devices and fresh human cadavers. Drift characteristics of each gauge with different excitation voltages were evaluated.

MATERIALS AND METHODS

A recent article by Eppinger provides a comprehensive summary on the chestband.[1] Briefly, it consists of a high-carbon steel alloy strip (140 cm x 1.25 cm x 0.025 cm) housing sixteen gauges. Each gauge is actually four strain gauges that make up four arms of a bridge. Gauge locations are shown in Figure 1. The steel strip with all the sixteen gauges is fixated with Flexane 80 liquid which is a two component urethane rubber for the casting of durable, resilient, medium to hard devices. Other details regarding the theoretical aspects of the chestband are given.[1]

To develop a protocol for use in deceleration sled tests, tests were conducted to determine the effects of strain gauge data with different excitation voltages and drift over an internal time consistent with reasonable sled testing periods. Three excitation volts were selected: 4 V, 6 V, and 10 V. Four volts of excitation was suggested by the manufacture (Denton Inc., Rochester Hills, MI), 6 volts was selected arbitrarily, and the highest voltage selected represented the requirements by the data acquisition system used to collect data in our laboratory. Drift pattern of all the gauges was evaluated by placing the chestband on a flat

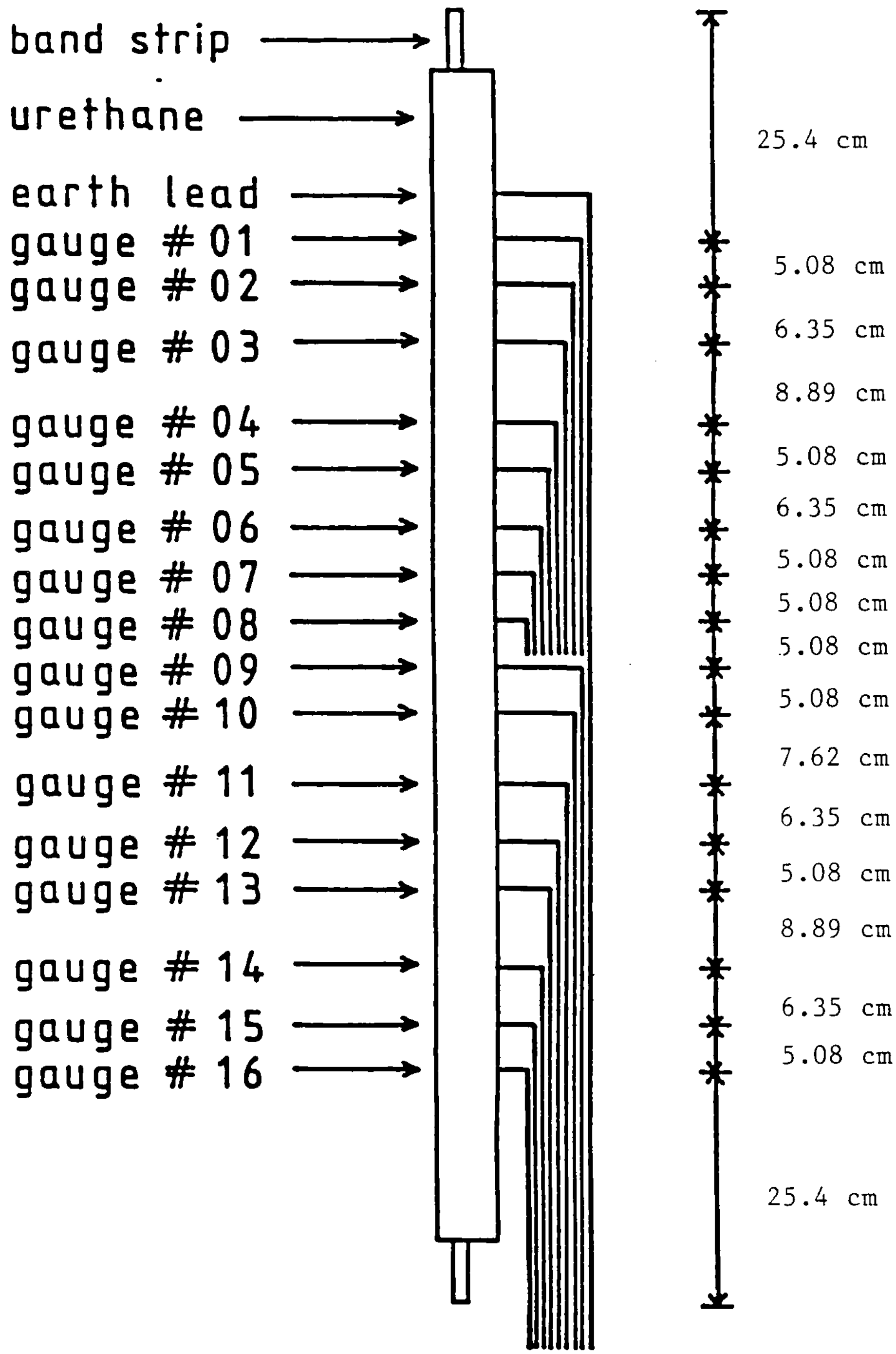

Figure 1: Schematic diagram illustrating the location of the strain gauges in a chestband (Adapted from Ref. #2).

surface (zero curvature) and by convoluting on a cylinder of 28 cm diameter. The drift characteristics were recorded for 8 of the 16 gauges for a period of 10 minutes. Initially, data were recorded at every 5 to 10 minute intervals for a period of 30 minutes, and measurements were then taken at every 15 to 20 minute intervals. A digital voltmeter was used to acquire the data.

Following these drift tests, static calibration tests were conducted on all the 16 gauges. Eleven different curvatures (one flat surface and 10 cylinders with different diameters) were used with 4 volt and 10 volt excitation voltages. The chestband was tensioned slightly by hanging weights (22.2 N) at its ends so that the instrumentfollows the curvature of the cylinder. Data were collected for each gauge using a digital voltmeter and voltage versus curvature plots were obtained. Results were analyzed using linear regression analysis procedures.

RESULTS AND DISCUSSION

The drift data as function of time obtained for the 8 gauges is included in Figure 2. As the plots clearly illustrate, the greatest amount of drift occurs in the first 10 to 30 minutes and then stabilizes, indicating that there is an initial "warm up" time for the instrument beyond which the drift is minimal. Furthermore, the pattern of drift does not have any particular bias with respect to any particular gauge or any particular voltage. The overall maximum drift for all the gauges, for all the three voltages and at all intervals of time considered in this study, was within 1.2%. Consequently, it can be concluded that the chestband protocol must allow for the initial stabilization process to take place in the instrument before it can be used to gather dynamic data.

A linear relationship was found to exist between the curvature and voltage output of the strain gauges ($0.992 \leq R^2 \leq 1.000$) for both the excitation voltages. Figure 3 illustrates a typical plot of the curvature versus output voltage for strain gauge #1 of the chestband for both the excitation voltages. Gradient of the plot indicates the gauge sensitivity. It can be inferred that, for a given curvature the output is higher with the 10 V excitation compared to the 4 V excitation.

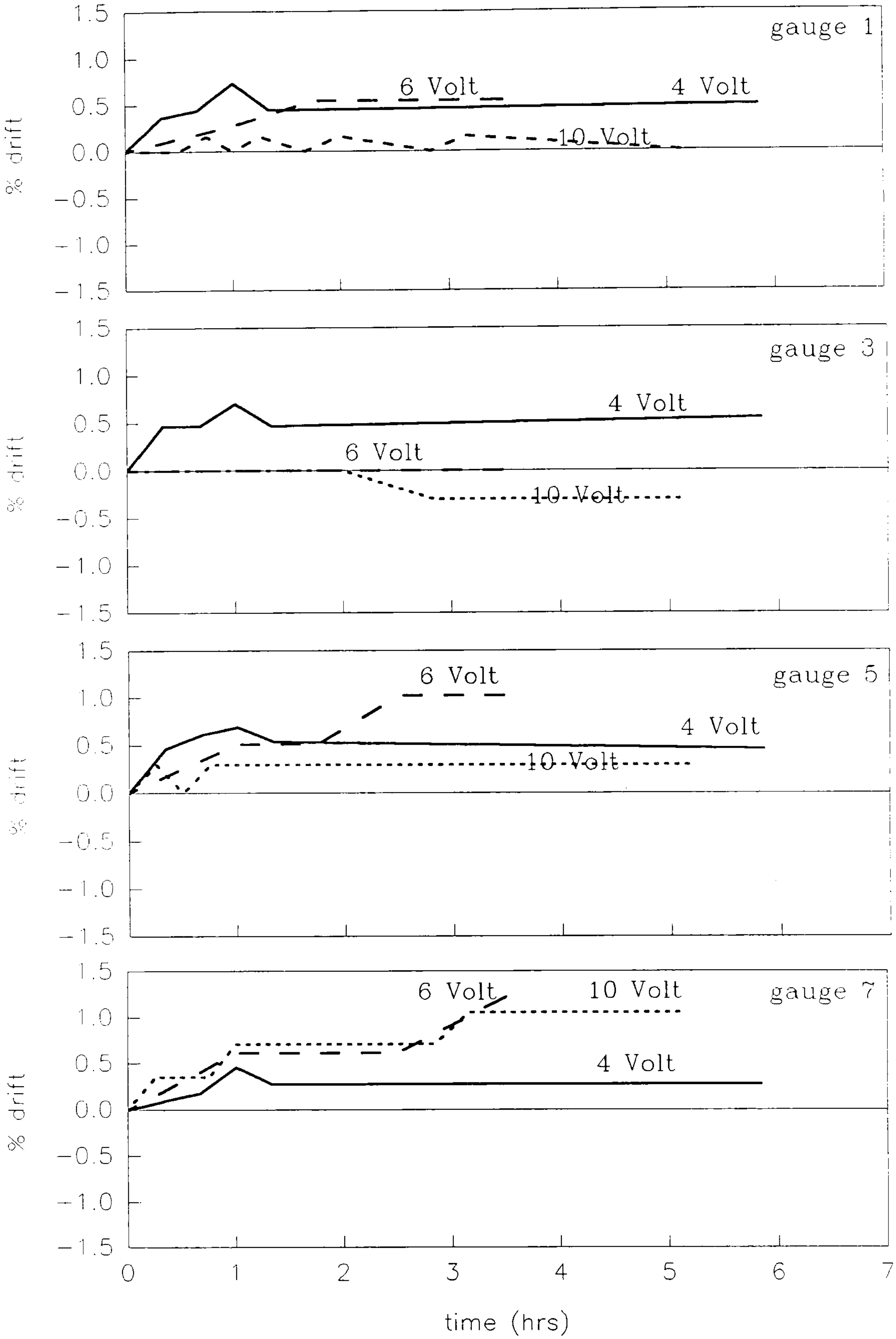

Figure 2a: Drift variation in the strain gauge data (gauges 1, 3, 5, 7) for three excitation voltages.

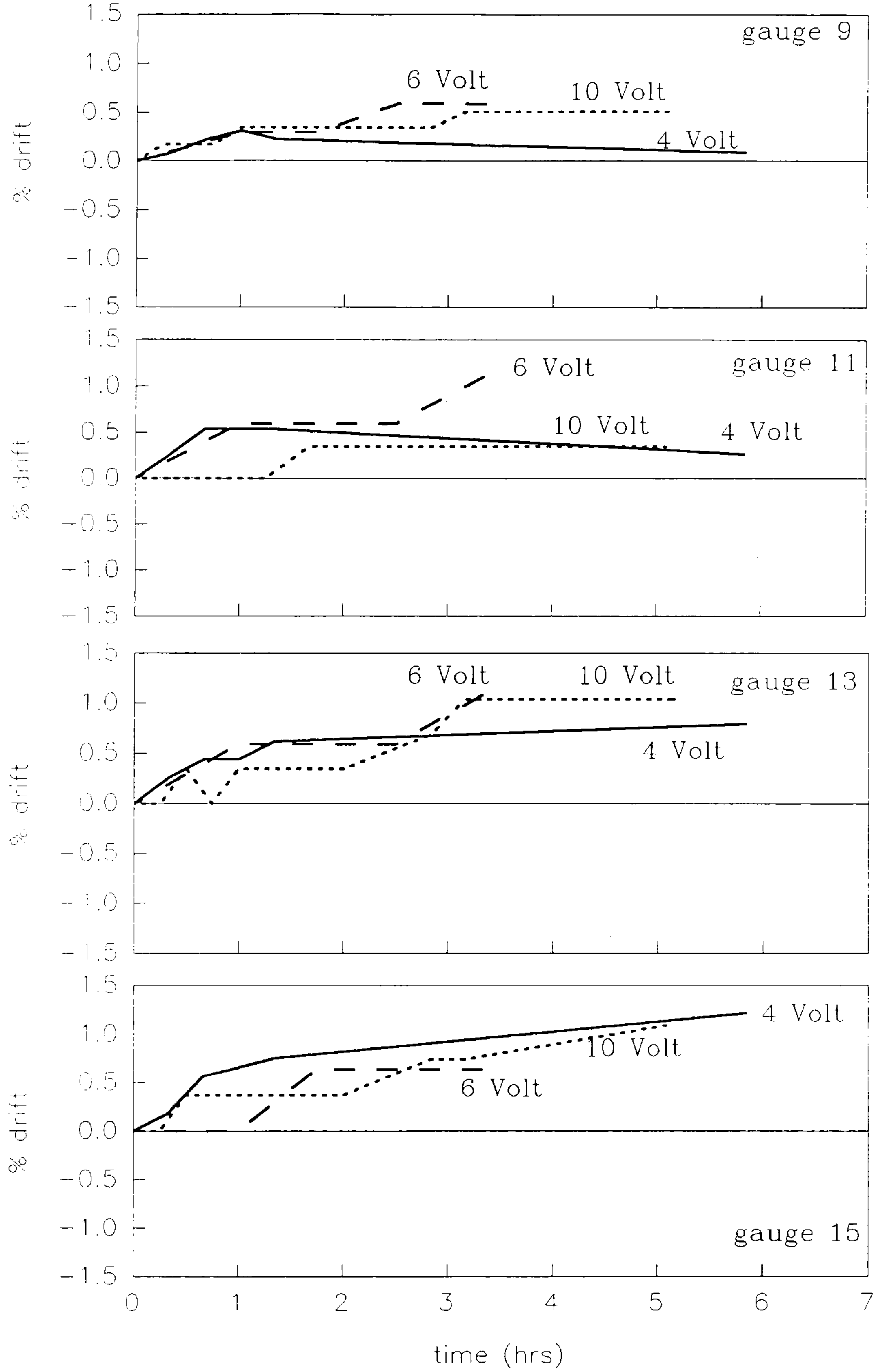

Figure 2b: Drift variation in the strain gauge data (gauges 9, 11, 13, 15) for three excitation voltages.

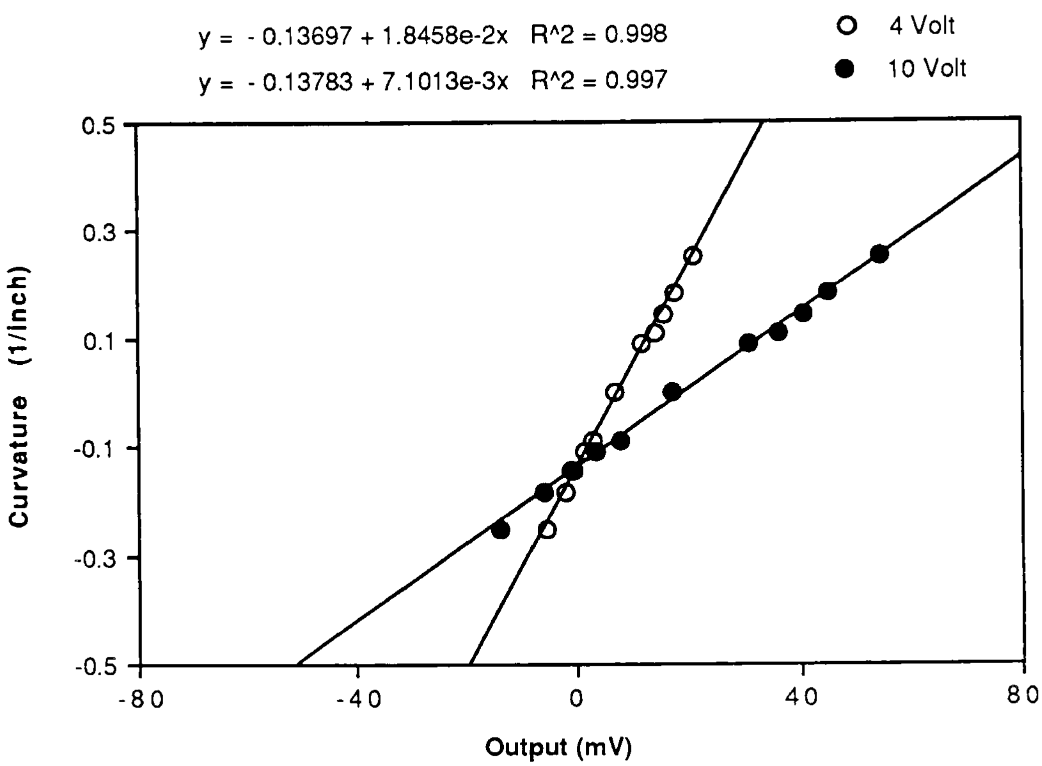

Figure 3: Linear regression plot illustrating the variation of curvature with output voltage for excitation voltages of 4 V and 10 V for strain gauge #1. Equations for both voltages are also indicated in the plot.

However, the sensitivity per voltage of excitation was not significantly different for 4 V or 10 V implying that either voltage can be used in dynamic tests with the chestband.

CONCLUSIONS

Based on the foregoing preliminary tests with the chestband, the following protocol is recommended for use in dynamic tests. Excitation voltage of 10 V can be used instead of the 4 V excitation suggested by the manufacturer. The instrument needs an initial "warm up" time of 15 to 30 minutes before the drift minimizes. An overall maximum drift of 1.2% was found in the chestband. It is suggested to zero all the gauges just prior to calibrate on a flat surface, and instrument the human surrogate last before conducting a dynamic test to gather deformation data from the chestband. As a precaution, following the dynamic test, it may be necessary to repeat the static calibration procedures described in this manuscript to insure that the strain gauges in the chestband have not entered the plastic range in order to be used for future experiments.

ACKNOWLEDGMENT

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PAPER: PRELIMINARY SLED TESTS WITH THE CHESTBAND

SPEAKER: Narayan Yoganandan, Medical College of Wisconsin

Question: John Melvin, General Motors Research Labs

You say that you can follow the deformations but I see no independent check. It looks like you used Hybrid III. Did you measure the chest deflections with the deflection potentiometer in the Hybrid III and how did they compare with what you say were the belt defections?

Answer: Narayan Yoganadan

The answer to the first question is that during the sled run, we did not have any other external or independent measurements to check whether the chest deflection we obtained from the chest band was accurate or not. However, we did some tests as I said in the last using some an MTS testing device where we were able to follow it reasonably well in the quasistatic mode. Second question, is we used a Hybrid... IV..if you want to call it IV ... that's fine, It's a combination of Hybrid II and Hybrid III because we have a Hybrid III head and neck and a Hybrid II torso and leg so what we did was we make a hybrid, hybrid of that. So, we did not have any independent measurements. So we hope to get a Hybrid III and then do your test.

Question: Larry Schneider, UMTRI

If you do use a Hybrid III, you'll be measuring internal deflection whereas your band is on the outside, measuring external deflection. There's about an inch or more of padding there that won't be accounted for. So, if you want to compare the two and validate using thte potentiometer in the Hybrid III, you'll have to have some other way of doing that, it would seem.

A: I think so.

Question: Richard Morgan, NHTSA

I know that earlier Wayne State indicated that if the radius of curvature was too sharp and there was not a gage in that vicinity, then perhaps they weren't tracking the deformation. Is it possible that in these experiments, the gage is exactly where the raise of curvature is?

A: You mean in the static experiments or in the sled test runs?

Q: In the static experiments.

A: In the static experiments the gages were right in the vicinity where the maximum deflection was being applied. In the case that I showed you the piston of the electrohydraulic testing device was right in between two gages.

Q: Two gages? Anybody from Wayne State care to comment? Would it have been different if we had chosen a different location?

Question: Warren Hardy, Wayne State University, Bioengineering Center

When you say that the head of your MTS testing machine or hydraulic loading device was positioned such as it was positioned between two gages... say the locations where you might generate the smallest radii of curvature, were the gages actually nearest the locations of the highest radii or did you set it so the highest curvatures would fall in between the gages so that you would be loading it in a least desirable fashion and still obtaining good results or were you loading it in a most desirable fashion to obtain these results?

A: These are the preliminary studies that we conducted, wherein the hemispherical wooden piece I showed you had a 1" flat strip on the bottom. So it is not a curve to curve contact. It's not a convex curvature to a concave curvature ... It's not a point contact. It's an area contact wherein the bottom portion of the wooden piece had a 1/2" width or so.. The wooden piece was positioned such that it was exactly in between the two gages. and the flat piece was applying the load so there was no gage underneath that point. However, we are conducting some experiments now. I don't have the results yet, but we are having a gage right at the point where the load is being applied. In other words, it is going to have a concentrated loading kind of situation in trying to see whether the chestband tracks the input deflection. However, I don't have the answers here yet.

Q: As a comment, in a conversation I had earlier about this, it seems that it might be a good idea to do some static tests where a series of mandrels of varying diameters would be used and you would actually take the band and rotate it around and have the gages fall in different locations on regions of high curvature and low curvature. Then, you might be able to determine, in some fashion, what the effect of the gage location was with respect to varying regions of curvature. In our case, we had a very controlled test and it was fairly easy to track what was going on. As you get more complicated, it becomes very difficult to tell exactly what is happening, and difficult to verify the performance of the chestband. Perhaps we could get a further understanding of how it could be improved by doing a static test of that nature.

A: We are planning a series of static tests to address that issue exactly. Hopefully, we can get some results for you.

Q: Steve Rouhana, General Motors Research Labs, Biomedical Science

I'm not sure if I may have missed something. You did the MTS tests and had a rigid back, is that correct? The torso was fixed rigidly to the platen of the MTS?

A: Yes.

Q: And the impactor was also rigid, is that correct?

A: It was just coming in contact with the manikin.

Q: The MTS is capable of giving you deflection versus time or displacement of the piston versus time, so, couldn't you use that to get a rough estimate of whether the band is actually tracking the motion?

A: The MTS has a computer controlled device which gives the displacement time signal from the LVTD which we have right attached in series with the piston. It works very well for the two results I showed you. As I said earlier, we're planning a host of experiments to look into quasi static behavior with different curvatures and things like that.